Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(2):298-302

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Application of microwave digestion/AAS for detection abnormal sound in valve mechanism of engine

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ABSTRACT

It is difficult to rapid detect the failure reason of abnormal sound in valve mechanism of engine based on the existing artificial experiential auscultation method and auxiliary instrument diagnosis method. Due to this, an innovative method of using atomic absorption spectrometry (AAS) was proposed to detect abnormal sound in valve mechanism of engine in this study. Engine lubricating oil of Santana 2000 with a traveled distance of 9000-40000 Km was considered as the experimental sample. For engine lubricating oil, sampling interval was about 1000 Km and sampling batches were 48, respectively. The titanium (Ti) content in engine lubricating oil sample was determined using AAS. Then, the database of Ti content in the lubricating oil came from same model and different mileages automobile engine was established. The results demonstrated that Ti content fluctuated in a certain range with automobile different mileages. In practical engineering, determination of Ti content in lubricating oil from abnormal sound automobile engine and comparison Ti content with their content change trend chart could help the maintenance person to judge types and locations of abnormal sound in valve mechanism of engine. Using this method could reduce the automobile maintenance and reparation costs and improve the failure diagnosis accuracy of abnormal sound in valve mechanism of engine.

Keywords: Atomic Absorption Spectrometry; Abnormal Sound; Valve Mechanism; Engine Lubricating Oil

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INTRODUCTION

The normal operation of the engine has some characteristics as following: engine speed is uniform; running sound of engine is slight; mechanical vibration of engine is rhythmic and voice of exhaust is normal[1]. However, when the running speed changes, normal engine is characterized by continuous change of sound intensity[2]. In addition, running speed is too steady and uninterrupted. If some abnormal phenomena appear, such as intermittent and irregular clash, friction sound and strong fluttering sound, etc. Those features are considered as abnormal sound of engine[3][4]. Abnormal sound indicates that some failures exist in engine and engine should be timely examined[5]. Hence, maintenance person should find out the reason of the engine failure and repair it in time[6].

Engine abnormal sounds in valve mechanism are mainly in valve knocking, sound of valve seat ring, tappet noise, timing gear sound and so on. In general, those abnormal sounds could be detected using artificial experiential auscultation method and auxiliary instrument diagnosis method. Artificial experiential auscultation method depended on the stethoscope, fire, oil test, and then integrated the change of opening of the valve[7][8]. Changes in sounds of valve mechanism are monitored and examined. In this process, it should observe the color and amount of exhausted gas from the valve mechanism timely, as well as the working states of engine[9][10]. Instrument diagnosis method mainly employed the electronic stethoscope to determine the failure location. Because there are many kinds of abnormal sounds in engine and different vibration sounds, sound pressure, amplitude and so on. Hence, once each friction pair of engine worn, fit clearance became larger or some accessories of engine loosed, which would produce abnormal sounds and vibrations and form specific sound level, sound pressure, and amplitude[11].[12] Those could be detected by using the abnormal sound electronic stethoscope. The above two methods in the detection of the engine abnormal sound in valve mechanism usually relied on the rich experience of automobile maintenance person. What's more, it also depended on their senses to quickly distinguish the abnormal or normal sound and find out the reasons and locations of abnormal sound. So, there are a mass of difficulties in this work.

Analysis of the reason for engine abnormal sound in valve mechanism, it could discover that the valve noise, sound of valve seat ring, tappet noise, timing gear sounds are usually caused by increased fit clearance which is led by the worn assembly. It had drastically different and could easily identify the locations between the timing gear sound and valve noise, sound of valve seat ring, tappet noise. Meanwhile, it is easy to distinguish the sound of valve seat ring with its characteristics of lower cylinder pressure than the standard value. It can be considered to judge from their material to differentiate valve sound and tappet noise. Because the valve materials generally come from heat resistant steel, which contain some components of chromium (Cr), iron (Fe) element. Valve tappet is generally made by chilled alloy cast iron, which is rich in Titanium (Ti), Manganese (Mn), Chromium (Cr), iron (Fe) and alloy elements. If the abnormal sounds come from the excessively worn valve tappet, Ti content in engine lubricating oil must beyond the normal value.

For this purpose, using microwave digestion/AAS method to detect abnormal sound in valve mechanism of engine was proposed. Firstly, engine lubricating oil sample was digested by using the microwave digestion instrument. Secondly, Ti content in automobile engine lubricating oil was determined by flame atomic absorption spectrophotometer method. Next, the database of Ti content in lubricating oil came from same model and different mileages automobile engine was established. Lastly, the normal range of Ti content in lubricating oil was calculated. This method could timely monitor the wear condition of engine valve tappet. And based on the content of main metal abrasive grain, it provided technical analysis basis for detection of engine valve tappet failure. This study presented a new method for detection of engine failure in valve mechanism, which reduced the automobile's maintenance costs and improve the accuracy of failure diagnosis in engine valve mechanism.

EXPERIMENTAL SECTION

1.1 Instruments and reagents
Atomic absorption spectrometer (Varian Company, USA, model FAS-240); All functional microwave chemistry work platform (Yiyao microwave chemistry technology co., LTD, Shanghai, model EXCEL); Electronic analytical balance (Saiduolisi co., LTD, Beijing); Titanium hollow cathode lamp (HITACHI Company, Japan).

Titanium standard stock solution 1000 $\mu g \cdot ml^{-1}$ (The national center for standard sample); Nitric acid (guaranteed reagent, GR); Experimental water was the ultrapure water.

1.2 Working condition of instrument
Working condition of instrument was as following: the detection wavelength of Titanium is 364.3 nm; slit width is 0.5 nm; lamp current is 20 mA; acetylene and air flow rate is 2.15 $L \cdot min^{-1}$ and 13.5 $L \cdot min^{-1}$, respectively.

1.3 Experimental methods
1.3.1 Source of the investigated sample

Experimental sample was engine lubricating oil which came from Santana 2000 with a mileage of 9000-40000 Km. the oil sampling interval was about 1000 Km. According to the automobile maintenance requirements, engine lubricating oil was changed per 8000 Km.

1.3.2 Sample preparation
1.0 g oil sample was accurately weighted and put them to a beaker in digestion tank, then 5 ml concentrated nitric acid was added in it. Meanwhile, sealing plug was fixed and put the digestion tank into microwave digestion system. The procedures of microwave digestion were exhibited in Table 1. After the microwave digestion, digestion tank was opened after cooling. It clearly seen that oil sample solution appeared yellow transparent liquid. Afterwards, digestion liquid was transferred to 25 ml volumetric flask and the nitric acid solution with 1 % was employed to metered volume. Lastly, the mixed liquor was shaken well for determination. The samples of controlled trials were prepared using the same method.

Table 1 Procedures of microwave digestion

Steps	Temperature/℃	Pressure/atm	Soaking time/min
1	140	15	4
2	170	20	4
3	200	30	4

RESULTS AND DISCUSSION

2.1 Drawing standard curve
Ti standard stock solution (1000 μg·mL^{-1}) was diluted using l% nitric acid solution into a series of concentration: 0, 20, 40, 80, 120 and 160 μg·mL^{-1}. According to working conditions of instrument and analysis method, absorbance of liquor was determined. After that, concentration was set as the abscissa (also called x axis) and absorbance was set as the ordinate (also called y axis), the regression function of Ti content was calculated as following:

$$y=0.0019x+0.0004 \quad (1)$$

with correlation coefficient: r=0.9996。

2.2 Verify the precision of the instrument
According to working conditions of instrument, the same Ti standard stock solution was measured six times, repeatedly. Then, relative standard deviation was calculated according to the determination results. And results showed that the relative standard deviation was lower than 1%, which revealed experimental instruments had a good accuracy.

2.3 Recovery rate test of adding Ti standard solution
Six same oil samples were accurately weighted and they were added appropriate amounts of Ti standard solution. According to working conditions of instrument and analysis method, the recovery rate of Ti was measured and listed in Table 2. The experimental results (in Table 2) demonstrated that the recovery rate of Ti was in 97.1%-101.4%.

Table 2 The results of Ti sample recovery test

No.	Ti content (μg)	Added Ti standard content (μg)	Estimated value (μg)	Recovery rate (%)
1	0.42	0.5	0.908	97.6
2	0.42	0.5	0.906	97.1
3	0.42	0.5	0.918	99.5
4	0.42	0.5	0.912	98.3
5	0.42	0.5	0.927	101.4
6	0.42	0.5	0.923	100.6

2.4 Determination results of sample
2.4.1 Results of determination
According to working conditions of instrument and analysis method, the Ti content in oil sample came from automobile with different mileage was measured and results were listed in Table 3.

Table 3 Ti content in oil samples came from automobile with different mileage

Mileage (1000km)	Ti content (μg·g^{-1})	Mileage (1000km)	Ti content (μg·g^{-1})
9	0.42	25	0.61
9	0.41	25	0.63
9	0.44	25	0.65
10	0.48	26	0.69
10	0.50	26	0.68
10	0.52	26	0.71
11	0.57	27	0.74
11	0.56	27	0.75
11	0.59	27	0.76
12	0.65	28	0.78
12	0.63	28	0.79
12	0.66	28	0.78
13	0.69	29	0.82
13	0.71	29	0.83
13	0.69	29	0.85
14	0.72	30	0.87
14	0.73	30	0.88
14	0.74	30	0.87
15	0.75	31	0.93
15	0.77	31	0.91
15	0.78	31	0.95
16	0.82	32	1.01
16	0.83	32	1.04
16	0.86	32	1.03
17	0.54	33	0.68
17	0.56	33	0.70

17	0.57	33	0.69
18	0.62	34	0.74
18	0.61	34	0.75
18	0.63	34	0.76
19	0.67	35	0.79
19	0.65	35	0.78
19	0.68	35	0.81
20	0.73	36	0.83
20	0.75	36	0.84
20	0.74	36	0.85
21	0.77	37	0.91
21	0.79	37	0.89
21	0.78	37	0.94
22	0.82	38	1.01
22	0.81	38	0.99
22	0.83	38	1.02
23	0.88	39	1.06
23	0.87	39	1.07
23	0.9	39	1.05
24	0.94	40	1.09
24	0.96	40	1.12
24	0.97	40	1.13

2.4.2 Analysis of the results

The above results (Ti content) were analyzed and showed in Fig. 1. As seen from Fig. 1, the maximum value of Ti content was 1.2 $\mu g \cdot g^{-1}$ and minimum value of Ti content was 0.4 $\mu g \cdot g^{-1}$. Ti content was fluctuated from 0.4 to 1.2 $\mu g \cdot g^{-1}$ along with the change of automobile mileage.

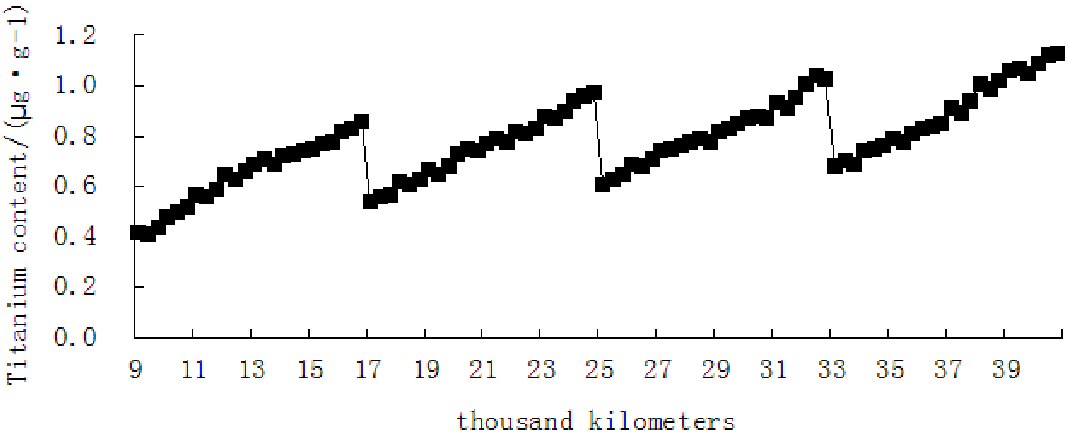

Fig. 1 Change trend of Ti content in different mileage

3. Verification of experimental results

A Santana 2000 car with 37000 Km mileages was employed to conduct this study. The car has some symptoms as following: the "clicking" or "snapped" sound was produced when the engine idle speed running; engine sound has no relation to the change of engine temperature and the single cylinder misfire; abnormal sound of engine became bigger accompany with engine speed increased. According to the above description, result of preliminary judgment was abnormal sound from valve mechanism.

Next, engine lubricating oil of the car was extracted and Ti content was measured using AAS method. The Ti content in engine lubricating oil was 2.5 $\mu g \cdot g^{-1}$. The value of Ti content was obviously higher than maximum value in above figure. Because of metallic titanium in valve tappet and the location and features of abnormal sound, it could conclude that the abnormal sound came from the valve tappet. Later, disassembling the engine, it could draw that the end of engine valve tappet was worn out seriously, which caused a big gap between the valve tappet and rocker arm. However, after changing the valve tappet, the failure phenomenon of abnormal sound disappeared. In addition, when changing the lubricating oil for a long time, the measurement result of Ti content in oil was in the normal range.

DISCUSSION

According to above case, Ti content in engine lubricating oil was determined by AAS method. If Ti content distributed in the normal range and did not obviously exceed the upper limit of change trend in above figure, it could rule out the abnormal sound of valve tappet. Sequentially, the scope of failure diagnosis was also diminished.

CONCLUSION

By atomic absorption spectrometry (AAS) method, Ti content in automobile engine lubricating oil was determined. And the database of Ti content in lubricating oil came from same model and different mileages automobile engine was established. Meanwhile, the results found that oil Ti content in lubricating oil fluctuated in the normal range. In practice, determination and comparison of Ti content in engine lubricating oil could provide technical analysis basis for the diagnosis of engine abnormal sound in valve mechanism. This study developed a new method for detection of engine abnormal sound in valve mechanism without disassembly, which reduced the automobile's maintenance costs and improve the accuracy of failure diagnosis in engine valve mechanism.

Acknowledgement
The authors would like to acknowledge the financial support provided by the Public Welfare Project of Technology Department of Zhejiang Province of China (2013C37078) and XinMiao Project of Zhejiang Province of China (2013R446002).

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